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Contents

EXECUTIVE SUMMARY

Wind power development scenarios are critical when trying to assess the impact of the demonstration at national and European level. The work described in this report had several objectives. The main objective was to prepare and deliver the proper input necessary for assessing the impact of Demo 4 – Storm management at national and European level. For that, detailed scenarios for offshore wind power development by 2020 and 2030 were required.

The aggregation level that is suitable for the analysis to be done is at wind farm level. Therefore, the scenarios for offshore wind power development offer details about the wind farms such as: capacity and coordinates. Since the focus is on the impact of storm fronts passage in Northen Europe, the offshore wind power scenarios were estimated only for the countries at North and Baltic Sea. The sources used are public sources, mentioned in the reference list. The scenarios are split in baseline – the conservative one, most likely to happen, and high – the optimistic scenario. During the time of the work, EWEA has published their estimation for 2020 and 2030. The scenarios estimated in this work are in good accordance with EWEA's.

A second task described in this work was to create a dataset containing forecast and realised wind power time series with hourly resolution. The database should cover all Europe, i.e. onshore and offshore and it will be further used in the project for the economic assessment impact, Tasks 16.2.2 and 16.2.3. For the onshore wind power development, the approach used in the TradeWind project has been used. This approach considered a first aggregation level for wind power at a grid node, and then a second aggregation at wind power regions. With this approach, wind power for a country can be expressed in one or several wind power nodes and one or several wind power regions. For onshore wind power, the estimated installed capacity was upscaled to meet the number published by EWEA in the Pure Power report.

Wind speed time series were extracted from the WRF dataset available at DTU Wind Energy and interpolated to the exact location of the wind power points with CorWind. Wind speed forecast errors were calculated using the Scenario Tree Tool developed in the WILMAR project.

Finally, wind power time series were simulated using the wind speed time series and adequate power curves. The resulted wind power time series were briefly analysed with respect to the distribution of wind power forecast errors and the results show that the wind power forecast error distribution manages to capture the area smoothening effect.

1 INTRODUCTION

This report is presenting the work done in the TWENTIES project work package 16, Task 16.2 Hydro balancing of North European wind power with large scale offshore development [1]:

> *This task deals with hydro balancing of the increased wind power variability in North Europe, which will be a consequence of the planned offshore wind power development in the area. It will quantify the expected variability with special focus on fast ramping, study potentials for hydro power in the Nordic countries and the Alps, and finally make grid impact and economic analysis.*

and subtask 16.2.1 North European 2020 offshore wind power variability:

> *This task will quantify the variability of the offshore wind power planned in North Europe by 2020 and later, taking into account the fast variability down to the minute time scale and the effect if the demonstrated storm controls. In Tradewind and other wind power integration studies, wind power has been represented by historical data and by Reanalysis data, which underestimates the offshore wind power variability significantly. Concerning historical wind power data, the experience with large offshore wind farms so far has clearly shown that the offshore wind power is significantly more variable than the on-shore wind power, first of all because offshore wind power is more concentrated geographically than existing on-shore wind power. The reanalysis data has also been shown to underestimate the wind power variability, typically in the time scale from minutes up to one day. In this view, Risoe has developed the Wind Power Time Series (WPTS) simulation model, which enables simulations of wind power time series, using Reanalysis data to provide the slow wind variability and adding the faster variability by a stochastic model. Both the reanalysis model and the stochastic model in WPTS take into account the correlation between wind speeds at neighbouring locations, and the phase delay of the wind speed variation in the wind direction.*

The work done in work package 16 aims at assesing the impact that the task forces will have on EU level [1]:

> *The objective of WP16 is to provide an integrated global assessment of the impact that the task forces will have on the EU level. Thus, WP16 will supplement the analysis in WP15 of the impact that the demonstrations have on a national level in the countries where they are performed. The basic idea is to use existing simulation models to support the quantification of this impact. The impact will be included in the simulations mainly by changing input parameters to the models. Thus, model development will be avoided, although some minor adjustments will be needed to include the effect of the demonstrators.*

2 OFFSHORE WIND POWER DEVELOPMENT

In Northern Europe, most of the future wind power development will be based on offshore wind farms.

In this context, by Northern Europe we mean the countries that are likely to have offshore wind installed in North Sea, Baltic Sea and/or Irish Sea: Belgium, Denmark, Estonia, Finland, France, Germany, Ireland, Latvia, Lithuania, Netherlands, Norway, Poland, Russia, Sweden, UK.

The wind power development scenarios have as target year 2020 and 2030. For each target year, a baseline and a high scenario were investigated. The baseline scenario is the one considered to be most-likely to happen. The installed capacity, for each considered country is presented in Table 1.

Table 1 Offshore wind power development scenarios per country

Country	MW installed end 2020		MW installed end 2030	
	Baseline	High	Baseline	High
Belgium	2,156	2,156	3,956	3,956
Denmark	2,811	3,211	4,611	5,811
Estonia	0	0	1,695	1,695
Finland	846	1,446	3,833	4,933
France	3,275	3,935	5,650	7,035
Germany	8,805	12,999	24,063	31,702
Ireland	1,155	2,119	3,480	4,219
Latvia	0	0	1,100	1,100
Lithuania	0	0	1,000	1,000
Netherlands	5,298	6,298	13,294	16,794
Norway	415	1,020	3,215	5,540
Poland	500	500	500	500
Russia	0	0	500	500
Sweden	1,699	3,129	6,865	8,215
UK	13,711	19,381	39,901	48,071
TOTAL	40,671	56,194	113,663	141,071

The results have been compared against the values published by EWEA in 2011 [2]. While there are some differences for some of the countries, the overall values are comparable. A detailed list of the individual wind farms/projects per country can be found in Table 2. The column marked 2020 tells if the specific project is estimated to be operating by 2020 (1) or not (0).

Table 2 Detailed offshore wind farm list for all scenarios

Country	**Scenario**		**Coordinates**		**2020**
	Base	High	Lat	Lon	y/n
United Kingdom					
Scroby Sands	60	60	52.645	1.787	1
Blyth	4	4	55.136	-1.49	1
Beatrice Demo	10	10	58.098	-3.078	1
Dogger Bank Project 1	1000	1400	54.931	1.828	1
Burbo Bank	90	90	53.488	-3.187	1
Docking Shoal	540	540	53.154	0.753	1
Dudgeon	560	560	53.249	1.39	1
Greater Gabband	504	504	51.883	1.935	1
Humber Gateway	230	230	53.644	0.923	1
Inner Dowsing	97	97	53.191	0.446	1
Kentish Flats	90	90	51.46	1.093	1
Lynn	97	97	53.136	0.458	1

North Hoyle	60	60	53.417	-3.448	1
Ormonde	150	150	54.088	-3.437	1
Race Bank	620	620	53.279	0.83	1
Rhyl Flats	90	90	53.378	-3.646	1
Robin Rigg	180	180	54.756	-3.71	1
Sherigham Shoal	317	317	53.135	1.147	1
Teeside	62	62	54.648	-1.095	1
Thanet	300	300	51.43	1.633	1
West of Duddon Sands	389	389	53.983	-3.463	1
Westernmost Rough	240	240	53.805	0.149	1
Barrow	90	90	53.991	-3.295	1
Forth Array	415	415	56.039	-1.929	1
Lincs	270	270	53.19	0.49	1
East Anglia One	1000	1200	52.234	2.478	1
London Array Phase 1	630	630	51.625	1.495	1
Atlantic Array WF	1000	1500	51.358	-4.525	1
Firth of Forth Phase 1	500	500	56.595	-1.82	1
Walney Phase 1	184	184	54.044	-3.522	1
Walney Phase 2	184	184	54.084	-3.613	1
MFEDA T. Telford	170	170	58.229	-2.655	1
MFEDA E. MacColl	170	170	58.186	-2.715	1
MFEDA R. Stevenson	170	170	58.144	-2.801	1
Gunfleet Sands 1+2	173	173	51.73	1.229	1
Gwynt Y Mor	576	576	53.46	-3.599	1
Triton Knoll	1200	1200	53.479	0.837	1
Navitus Bay WP	500	500	50.478	-1.756	1
Burbo Bank extension	234	234	53.483	-3.273	1
Kentish Flats extension	51	51	51.45	1.079	1
Galloper WF	504	504	51.876	2.039	1
Irish sea	4000	2000	53.762	-4.395	1
Hornsea 1	2000	600	53.912	1.797	1
Hornsea 2	0	600	53.908	2.086	1
NOVA project	0	1000	55.423	-1.284	1
London Array Phase 2	0	370	51.678	1.59	1
Dogger Bank	7600	8000	55.293	2.478	0
Irish Sea	4000	4000	53.782	-4.395	0
Islay	690	690	55.766	-6.743	0
Argyll Array	1800	1500	56.403	-7.108	0
East Anglia 2-6	3800	4000	52.638	2.556	0
Rampion (Hastings)	500	500	50.659	-0.196	0
Hornsea	1800	2000	53.965	1.48	0
Other areas 1	0	1000	54.918	-5.4	0
Other areas 2	0	1000	58.306	-7.688	0
Other areas 3	0	1000	58.031	-5.958	0
Other areas 4	0	1000	56.105	-6.831	0

Other areas 5	0	1000	60.435	-1.94	0
Other areas 6	0	1000	60.185	-0.729	0
Other areas 7	0	1000	57.831	-2.299	0
Other areas 8	0	1000	54.532	-4.066	0
Germany					
Alpha Ventus	60	60	54.013	6.605	1
Borkum Riffgrund	0	320	53.967	6.554	1
Amrumbank West	400	400	54.522	7.708	1
Nordsee Ost	295	295	54.444	7.682	1
Meerwind Ost	144	144	54.401	7.731	1
Butendiek	288	288	55.019	7.774	1
Riffgat	108	108	53.692	6.475	1
BARD offshore 1	400	400	54.355	5.98	1
Austerngrund	520	520	54.427	5.745	1
MEG offshore 1	400	400	54.039	6.555	1
Meerwind Sud	144	144	54.378	7.669	1
Albatros	400	400	54.52	6.287	1
Wikinger	400	400	54.834	14.068	1
Arkona-Becken SO	400	400	54.782	14.121	1
Breitling	3	3	54.161	12.131	1
Beltsee	125	125	54.438	11.508	1
GEOFReE	25	25	54.249	11.397	1
Notos	265	265	54.504	6.268	1
DanTysk	288	288	55.137	7.2	1
Borkum Riffgrund W 1	280	280	54.047	6.234	1
Strom-Nord	0	270	54.874	13.852	1
Sea Storm 1	400	400	54.602	5.948	1
EnBW Baltic 2	288	288	54.982	13.162	1
EnBW Baltic 1	48	48	54.609	12.651	1
Sea Wind 4	0	390	54.612	6.071	1
Sea Wind 3	0	285	54.668	6.015	1
Bight Power 1	400	400	54.269	6.169	1
Hooksiel	5	5	53.637	8.104	1
EnBW Hohe See	400	400	54.444	6.329	1
Innogy Nordsee Phase 1	332	332	53.982	6.828	1
Innogy Nordsee Phase 2	0	332	54.025	6.864	1
Innogy Nordsee Phase 3	0	332	54.073	6.854	1
Borkum Riffgrund 2	0	480	53.957	6.494	1
Nordlicher Grund	320	320	55.056	6.933	1
Sandbank 24	288	288	55.193	6.859	1
He Dreiht 1	595	595	54.365	6.186	1
Deutsche Bucht	210	210	54.305	5.799	1
Veja Mate	0	400	54.317	5.871	1
Nordergrunde	91	91	53.838	8.166	1
Aiolos	0	985	54.721	6.369	1

GAIA 5	0	400	55.039	6.406	1
Gode Wind 1	231	231	54.016	6.983	1
Gode Wind 2	252	252	54.059	7.042	1
H2-20	400	400	55.713	4.137	0
Sea Wind 2	300	300	54.503	6.25	0
Strom-Nord	270	270	54.874	13.852	0
Citrin	400	400	54.534	5.897	0
Delta Nordsee 1	240	240	54.037	6.765	0
Delta Nordsee 2	160	160	54.04	6.779	0
Borkum Riffgrund 2	480	480	53.957	6.494	0
Veja Mate	400	400	54.317	5.871	0
GAIA 5	400	400	55.039	6.406	0
Hochsee Testfeld H.	95	95	54.489	7.696	0
Sandbank 24 extension	200	200	55.202	6.855	0
KASKASI	320	320	54.437	7.779	0
Arcadis Ost 1	350	350	54.833	13.595	0
Adlergrund 500	72	72	54.818	14.095	0
Adlergrund GAP	186	186	54.822	14.129	0
Arkona-Becken SO	500	500	54.782	14.121	0
Nordpassage	400	400	55.181	7.126	0
Aquamarin	400	400	54.26	5.95	0
Global Tech 2	400	400	54.284	6.199	0
Area C 1	400	400	54.316	6.539	0
Area C 2	400	400	54.281	6.733	0
Bernstein	400	400	54.478	5.873	0
Gannet	400	400	54.39	6.578	0
Heron	400	400	54.4	6.671	0
Borkum Riffgrund W 2	215	215	54.063	6.172	0
OWP West	400	400	54.029	6.179	0
GAIA 1	400	400	54.993	6.33	0
Seewind	150	150	54.96	13.194	0
Horizont 3 (West)	355	355	54.806	6.371	0
Horizont 2 (Ost)	380	380	54.885	6.317	0
GAIA 2	200	200	54.835	6.173	0
GAIA 3	400	400	54.783	6.127	0
GAIA 4	340	340	54.754	6.216	0
Diamant	1040	1040	54.63	5.242	0
Global Tech 3	105	105	54.291	6.296	0
Beta Baltic	115	115	54.277	11.403	0
Bight Power 2	400	400	54.274	6.286	0
Adlergrund Nordkap	155	155	54.849	14.062	0
EnBW Hohe See	500	500	54.444	6.329	0
Baltic Power	480		54.967	13.221	0
He Dreiht 2	140	140	54.322	6.207	0
Borkum West 2 Phase 1	200		54.046	6.457	0

Global Tech 1	1000	1000	54.507	6.364	0
Sea Wind 1	220	220	54.522	6.395	0
Gode Wind 3	90	90	54.037	7.11	0
Arkona See Sud	0	200	54.78	13.868	0
Baltic Eagle	0	480	54.828	13.865	0
Area C 3	0	400	54.279	6.905	0
Seagull	0	400	54.391	6.746	0
Petrel	0	400	54.379	6.867	0
Meerwind West	0	805	54.438	7.424	0
Borkum West 2 Phase 1	0	200	54.046	6.457	0
Borkum West 2 Phase 2	0	200	54.046	6.457	0
Euklas	0	1040	54.632	5.1	0
Denmark					
Anholt	400	400	56.604	11.209	1
Avedøre Holme	11	11	55.601	12.464	1
Frederikshavn	11	11	57.443	10.562	1
Horns Rev A HR3	200	200	55.647	7.791	1
Horns Rev A HR4	0	200	55.71	7.849	1
Horns Rev A HR5	0	200	55.789	7.88	1
Horns Rev 1	160	160	55.486	7.84	1
Horns Rev 2	209	209	55.6	7.582	1
Kriegers Flak A K2	200	200	55.05	12.984	1
Kriegers Flak A K3	200	200	54.994	12.822	1
Kriegers Flak A K4	200	200	55.005	13.068	1
Kriegers Flak B K1	200	200	55.077	12.874	1
Middelgrunden	40	40	55.689	12.668	1
NearshoreLAB	36	36	57.457	10.637	1
Nysted (Rødsand 1)	166	166	54.549	11.714	1
Ringkøbing Fjord B RK 3	200	200	56.018	7.71	1
Rødsand 2	207	207	54.555	11.548	1
Rønland	17	17	56.662	8.22	1
Samsø	23	23	55.723	10.584	1
Sprogø	21	21	55.343	10.958	1
Store Middelgrund MG1	200	200	56.5	12.095	1
Tunø Knob	5	5	55.968	10.355	1
Vindeby	5	5	54.969	11.129	1
Århus Bugt	100	100	56	10.48	1
Horns Rev A HR6	200	200	55.787	7.578	0
Jammerbugt A J3	200	200	57.288	9.22	0
Jammerbugt A J4	200	200	57.328	9.332	0
Jammerbugt B J1	200	200	57.393	8.827	0
Jammerbugt B J2	200	200	57.429	8.943	0
Ringkøbing Fjord A RK1	200	200	56.409	7.734	0
Ringkøbing Fjord B RK4	200	200	56.075	7.636	0
Rønne Banke RB1	200	200	54.891	14.749	0

Rønne Banke RB2	200	200	54.927	14.653	0
Horns Rev A HR7	0	200	55.644	7.429	0
Ringkøbing Fjord A RK2	0	200	56.324	7.736	0
Ringkøbing Fjord B RK4	0	200	56.075	7.636	0
Ringkøbing Fjord C RK5	0	200	56.21	7.741	0
Netherlands					
Q10	153	153	52.405	4.154	1
Den Helder I	468	468	52.897	3.67	1
Brown Ridge Oost	282	282	52.717	3.468	1
Egmond an Zee	108	108	52.606	4.419	1
Prinsess Amalia (Q7)	120	120	52.588	4.223	1
Beaufort (Katwijk)	340	340	52.305	3.971	1
Scheveningen Buiten	212	212	52.192	3.751	1
Q4	78	78	52.675	4.25	1
West Rijn	259	259	52.266	3.634	1
Breevertien II	349	349	52.571	3.602	1
Lely	2	2	52.797	5.119	1
Irene Vorrink	17	17	52.598	5.589	1
Tromp Binnen	295	295	52.826	3.528	1
Noordoostpolder 1	190	190	52.721	5.583	1
Noordoostpolder 2	50	50	52.796	5.617	1
ZeeEnergie	300	300	54.034	5.884	1
Clearcamp	275	275	54.035	5.966	1
Buitengaats	300	300	54.038	6.041	1
Borssele DZ 1	500	500	51.7	2.995	1
Borssele DZ 2	0	500	51.694	3.131	1
Hollandse kust DZ 1	1000	500	52.556	4.058	1
Hollandse kust DZ 2	0	250	52.545	3.879	1
Hollandse kust DZ 3	0	250	52.126	3.401	1
Hollandse kust DZ 4	500	500	52.842	4.1	1
Okeanos	158	158	52.685	4.247	0
Cornelia	438	438	54.334	5.18	0
Wieringermeerdijk	100	100	52.824	5.136	0
FLOW Demo	300	300	53.08	3.65	0
Hollandse kust DZ 5	250	250	52.112	3.218	0
Hollandse kust DZ 6	250	250	52.191	3.318	0
Hollandse kust DZ 9	500	500	52.909	4.1	0
Ijmuiden DZ 1	1000	1000	52.901	3.747	0
Ijmuiden DZ 2	1000	1000	52.853	3.688	0
Ijmuiden DZ 3	1000	1000	52.886	3.592	0
Ijmuiden DZ 4	1000	1000	52.935	3.652	0
Ijmuiden DZ 5	1000	1000	52.814	3.47	0
Borssele DZ 2	500	500	51.694	3.131	0
Borssele DZ 3	0	500	51.71	2.85	0
Hollandse kust DZ 7	0	250	52.18	3.433	0

Hollandse kust DZ 8	0	500	52.543	4.197	0
Ijmuiden DZ 6	0	1000	52.781	3.549	0
Waddeneilanden 1	0	250	53.895	5.696	0
Waddeneilanden 2	0	250	53.9	6.04	0
Waddeneilanden 3	0	250	53.9	5.2	0
Sweden					
Stora Middelgrund	540	540	56.607	12.113	1
Petlandsskar	90	90	63.547	20.335	1
Yttre Stengrund	10	10	56.167	16.021	1
Kriegers Flak 2	640	640	55.07	13.103	1
Storgrundet	265	265	61.145	17.464	1
Klocktarnan	660	660	65.07	22.03	1
Bockstigen	3	3	57.036	18.15	1
Utgrunden I	11	11	56.344	16.28	1
Lillgrund	110	110	55.511	12.779	1
Kaarehamn	0	50	56.984	17.022	1
Skottarevsprojektet	150	150	56.824	12.346	1
Trolleboda	180	180	56.298	16.176	1
Taggen Vindpark	300	300	55.862	14.566	1
Seawind Lake Vanern	90	90	59.223	13.307	1
Vindpark Vanern	30	30	59.262	13.387	1
Finngrunden	1500	1500	60.997	18.24	0
Soedra Midsjoebanken	700	1000	55.672	17.267	0
Utgrunden II	86	86	56.375	16.266	0
Blekinge Offshore AB	1500	2500	55.932	15.021	0
Norway					
Hywind	2	2	59.14	5.032	1
SWAY 10 MW Text Turbine	10	10	60.556	4.888	1
SWAY 2.6 MW Test Turbine	3	3	59.146	5.109	1
Utsira Phase 1	0	25	59.259	4.936	1
Utsira Phase 2	0	280	59.295	4.527	1
Fosen Offshore Fase 2	0	300	64.274	10.175	1
Karnoey WT Demo	10	10	59.163	5.18	1
Rennesoey WT Demo	10	10	59.062	5.612	1
Kvitsoey WT Demo	10	10	59.075	5.405	1
Testp. Fure	5	5	62.083	5.153	1
Testp. Kvalheimsvika	5	5	61.962	4.985	1
Testom. Bukketjuvane	10	10	62.224	4.899	1
Havsul I Phase 1	50	50	62.805	6.3	1
Havsul I Phase 2	300	300	62.829	6.384	1
Salvaer Offshore VV	100	200	66.624	12.227	0
Gimsoey Offshorepark	100	200	68.372	14.127	0
Vannoeya HV III	100	200	70.292	19.752	0
Sandskallen - Soeroeya N.	100	200	70.943	22.551	0
Auvaer	100	200	69.928	18.181	0

Froeyagrunnene	100	150	61.748	4.682	0
Nordmela	100	200	69.148	15.436	0
Nordoeyan - Ytra Vikna	100	200	64.894	10.503	0
Soerlige Nordsjoe I	1000	1250	57.42	3.533	0
Stadthavet	500	1000	62.281	3.732	0
Utsira Nord	500	720	59.276	4.54	0
Poland					
P4 a	500	500	54.5	14.5	1
P1	600	600	54.3	15.3	0
P2	300	300	54.55	16.3	0
P3	300	300	54.7	16.15	0
P4 b	300	300	54.5	15.5	0
P5	300	300	54.6	15.2	0
P6	300	300	55.2	17.1	0
P7	300	300	54.9	17.2	0
P8	300	300	55	18.3	0
P9	300	300	54.8	18.75	0
P10	300	300	54.9	28.9	0
P11	300	300	55.05	18.5	0
P23	300	300	55.2	17.3	0
P24	300	300	55.3	17.8	0
P25	300	300	55.5	17.9	0
P26	300	300	55.3	17.1	0
France					
Poweo	200	200	48.727	-2.589	1
Cote d'Abatre II	400	400	49.996	0.566	1
Cote d'Abatre	105	105	49.932	0.587	1
Deux Cotes	705	705	50.147	1.151	1
Le Havre	260	260	49.588	0.08	1
Calvados	250	250	49.437	-0.554	1
Hautes Falaises	300	300	49.866	0.268	1
Maia	250	250	49.554	-0.559	1
Le Banche	72	72	47.196	-2.467	1
Fecamp GDF Suez	300	300	49.928	0.228	1
Nass and Wind	240	240	48.768	-2.515	1
WINFLO	3	3	47.619	-3.493	1
Banc de Guerande	400	400	47.151	-2.655	1
Fecamp	200	200	49.892	0.227	1
Saint-Nazaire	250	250	47.158	-2.602	1
Cherbourg	400	400	49.785	-1.612	0
Boulogne	25	25	50.672	1.504	0
Baie de Seine	300	300	49.471	-0.531	0
Des Minquiers	200	200	48.813	-2.019	0
Haute Normandie	280	280	49.967	0.704	0
3B	210	210	50.381	1.305	0

d'Aise	100	100	47.519	-3.313	0
Neoen	100	100	49.275	-1.796	0
Les Grunes	100	100	49.221	-1.785	0
Des Deux Iles	0	600	46.854	-2.461	0
Portes en Re	0	120	46.244	-1.627	0
Helene	0	315	47.614	-4.061	0
Brianna	0	350	47.663	-3.456	0
Belgium					
Zone 7	300	300	51.707	2.722	1
Belwind Phse 1	165	165	51.67	2.802	1
Belwind Phase 2	165	165	51.664	2.817	1
Seastar	246	246	51.634	2.859	1
Eldepasco	216	216	51.619	2.901	1
RENTEL	288	288	51.591	2.943	1
Thornton Bank I	30	30	51.544	2.938	1
Thornton Bank II	148	148	51.563	2.985	1
Thornton Bank III	148	148	51.538	2.921	1
North Sea Power	450	450	51.527	3.014	1
Zone 2	1800	1800	51.45	2.45	0
Ireland					
Codling Wind Park	900	900	53.104	-5.782	1
Oriel Wind Farm	330	330	53.918	-6.068	1
Sceirde Rocks	100	100	53.279	-9.963	1
Arklow Bank Phase 1	25	25	52.789	-5.949	1
Arklow Bank Phase 2	400	400	52.811	-5.95	1
Dublin Array	625	364	53.259	-5.944	1
Codling WP Extension	1000	1000	53.044	-5.819	0
Arklow Phase 2	100	100	52.811	-5.93	0
Supplementary capacity 1	0	500	51.5	-9	0
Supplementary capacity 2	0	500	52.5	-10	0
Finland					
Oulun - Haukiputaan alue 1	150	150	65.219	24.994	1
Pori 1	3	3	61.624	21.325	1
Pori 2	160	160	61.639	21.332	1
Kemi Ajos Test Turbine	3	3	65.638	24.524	1
Kemi Ajos I	15	15	65.655	24.513	1
Kemi Ajos II	15	15	65.652	24.546	1
Kristinestad	100	400	62.238	21.226	1
Suurhiekka	100	400	65.292	24.651	1
Kemi Ajos III	300	300	65.619	24.552	1
Tornio	225	225	65.739	24.237	0
Oulusalo - Hailuoto	180	180	65.012	25.131	0
Raahe - Maanahkiainen	300	500	64.595	24.145	0
Oulun - Haukiputaan alue 2	650	650	65.179	24.954	0
Inkoon - Raaseporin	300	230	59.859	23.888	0

Raahe - Pertunmatala	72	300	64.753	24.272	0
Raahe - Ulkonahkiainen	140	72	64.795	24.445	0
Kristinestad	300	210	62	21.226	0
Suurhiekka	300	600	65.1	24.651	0
Ostra Skargaarden	120	120	60.134	20.889	0
Siipyy	400	400	62.075	21.12	0
Estonia					
Hiiumaa	700	700	59.084	22.282	0
Neugrund	190	190	59.319	23.551	0
Kihnu South	560	560	58.001	24.034	0
Kihnu SouthWest	245	245	58.063	23.703	0
Lithuania					
L1	200	200	55.984	20.443	0
L2	200	200	55.907	20.86	0
L3	200	200	55.771	20.773	0
L4	200	200	55.617	20.95	0
L5	200	200	55.457	20.471	0
Latvia					
Liepaja	900	900	56.732	20.947	0
Baltic Wind Park	200	200	56.82	20.771	0

The geographical distribution of the offshore wind power, for each target year, can be seen in Figure 1

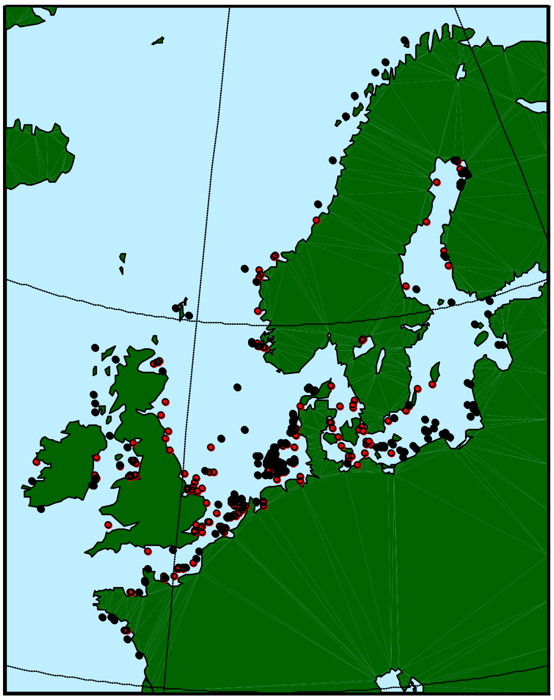

Figure 1 Offshore wind farms in 2020 (red) and 2030 (red+black)

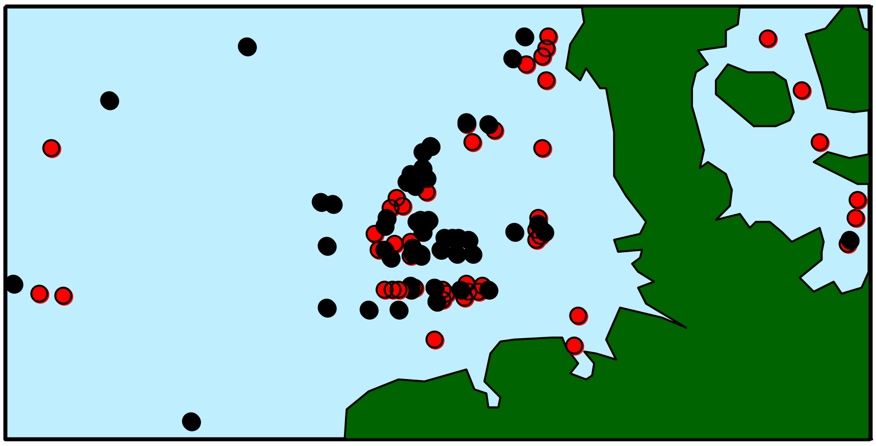

Figure 2 Detailed view of South-East part of North Sea – North-West Germany and West Denmark

In order to be give an impression of the extra offshore wind farms considered in the 2030 scenario, a zoom in the South-East part of the North Sea (Germany and Denmark coastlines) is given in Figure 2.

For the onshore wind power development, the approach used was adopted from the TRADEWIND project [3]. The onshore wind power is aggregated in several regions, with the regions belonging to a grid zone. A country would then consist of one or more grid zones and/or wind regions. The aggregated wind farms together with the grid zones are shown in Figure 3, taken from [4]. For 2020, the aggregated wind power installed in each region was upscaled so that the total onshore wind power reaches the values given in [2]. For 2030, the values were upscaled, proportionally, so it would reach the estimated EWEA's values. Keeping that in mind, the values for onshore wind power are given in Table 2.

Table 2 Onshore aggregated wind power

Country	Region	MW installed end 2020		MW installed end 2030	
		Baseline	High	Baselin e	High
Austria	**A1**	3500	4000	4707	4914
Belgium	**B**	2100	2500	2824	3071
Bulgaria	**BU**	206	240	277	295
	BU	291	340	392	418
	BU	2503	2920	3366	3587

Chech Republic	**CZ**	565	635	759	780
	CZ	659	741	886	911
	CZ	376	424	506	520
Denmark	**DK_E**	1334	1443	1794	1794
	DK_W	2366	2557	3181	3181
Finland	**SF1**	900	900	1210	1210
	SF2	600	600	807	807
France	**F7**	3351	3527	4506	4506
	F1	3351	3527	4506	4506
	F2	3351	3527	4506	4506
	F3	4021	4233	5408	5408
	F5	653	688	879	879
	F4	653	688	879	879
	F6	3619	3810	4867	4867
Germany	**D1**	16408	16808	22064	22064
	D2	9601	9836	12912	12912
	D3	4007	4105	5389	5389
	D4	515	528	693	693
	D5	4866	4985	6544	6544
	D5	4866	4985	6544	6544
	D6	736	754	990	990
Great Britain	**GB**	975	1050	1311	1311
	GB	975	1050	1311	1311
	GB	650	700	874	874
	GB	6240	6720	8391	8391
	GB	4160	4480	5594	5594
Greece	**GR**	3250	4150	4370	5098
	GR	3250	4150	4370	5098
Hungary	**HU**	600	600	807	737
Italy	**I1**	542	614	729	755
	I3	361	410	486	503
	I3	1627	1843	2187	2265
	I3	7590	8602	10207	10568
	I3	4880	5530	6562	6794

Luxemburg	**L**	126	126	169	155
Netherlands	**N**	3500	3500	4707	4300
Norway	**NO1**	420	420	565	516
	NO2	1350	1820	1815	2236
	NO2	470		632	0
	NO3	470	940	632	1155
	NO3	470		632	0
Poland	**P1**	6667	8000	8965	9828
	P2	3333	4000	4483	4914
Portugal	**P**	2259	2711	3038	3330
	P	3539	4247	4759	5217
	P	1536	1843	2066	2265
	P	15	18	20	22
	P	151	181	203	222
Irland	**IR**	1250	1500	1681	1843
	IR	1250	1500	1681	1843
	IR	1250	1500	1681	1843
	IR	1250	1500	1681	1843
Romania	**RO**	812	947	1092	1163
	RO	1059	1235	1424	1518
	RO	265	309	356	379
	RO	141	165	190	202
	RO	547	638	736	784
	RO	176	206	237	253
Slovakia	**SK**	571	714	768	877
	SK	57	71	77	88
	SK	171	214	231	263
Slovenia	**SV**	465	651	625	800
	SV	35	49	47	60
Spain	**E1**	926	974	1245	1245
	E1	397	417	534	534
	E1	2015	2118	2710	2710
	E1	2015	2118	2710	2710
	E1	2015	2118	2710	2710

	E1	6549	6885	8807	8807
	E1	771	810	1036	1036
	E1	578	608	778	778
	E2	1411	1484	1898	1898
	E2	1411	1484	1898	1898
	E2	1411	1484	1898	1898
	E2	1328	1396	1786	1786
	E2	1328	1396	1786	1786
	E2	1942	2042	2612	2612
	E3	6020	6329	8095	8095
	E3	1687	1773	2268	2268
	E3	1687	1773	2268	2268
	E3	165	174	222	222
	E3	827	869	1112	1112
	E4	1367	1437	1839	1839
	E4	1367	1437	1839	1839
	E4	1367	1437	1839	1839
	E4	413	435	556	556
Sweden	**SE2**	2222	2963	2988	3640
	SE2	1111	1481	1494	1820
	SE3	1333	1778	1793	2184
	SE3	1333	1778	1793	2184
Switzerland	**S1**	300	300	403	369

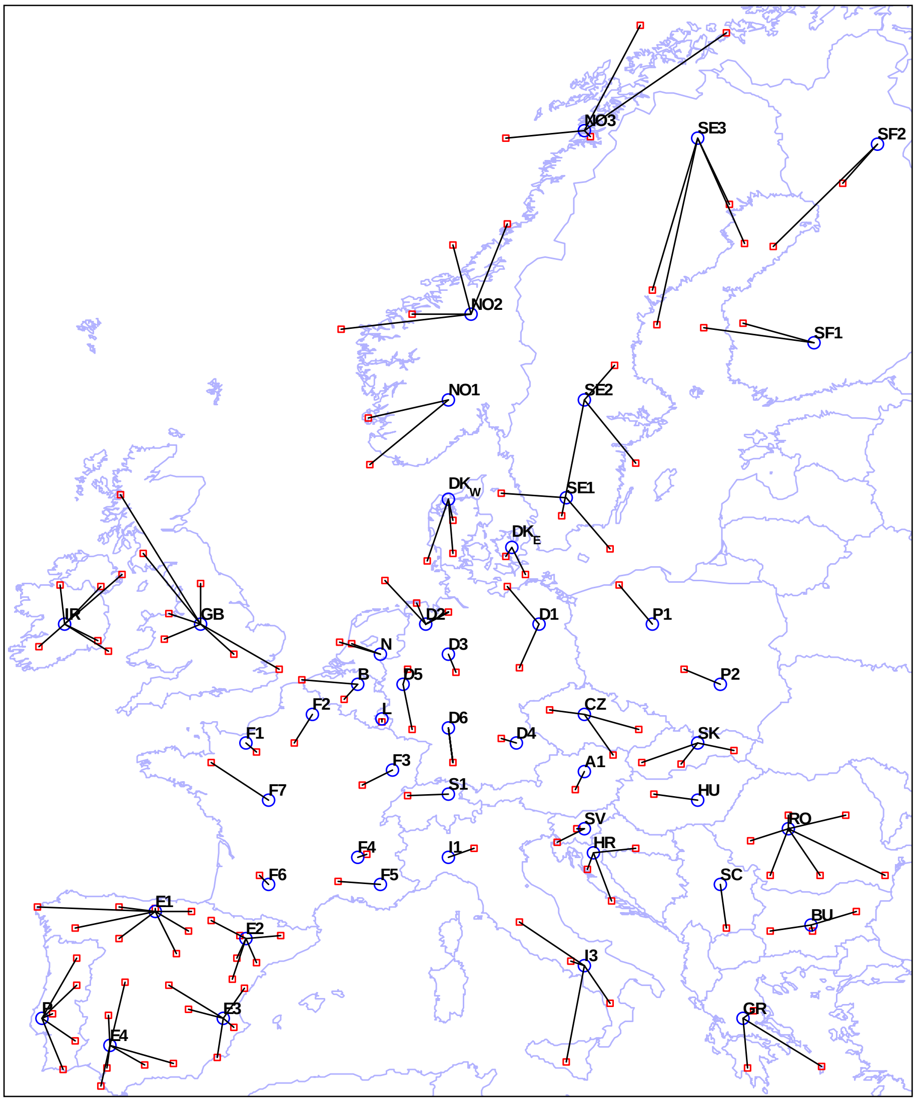

Figure 3 Locations of aggregated wind farms from [4] (Red squares) and their corresponding grid zones (shown as lines to the blue circles). The lines do not represent physical connections

The overall wind power development at pan-European level is given in Figure 4 for the baseline scenario and in Figure 5 for the high scenario. According to those, wind power in Europe will reach a total of 235 GW, in the conservative case, or 267 GW in the high, by 2020 and 369 GW or 405 GW, respectively, by 2030.

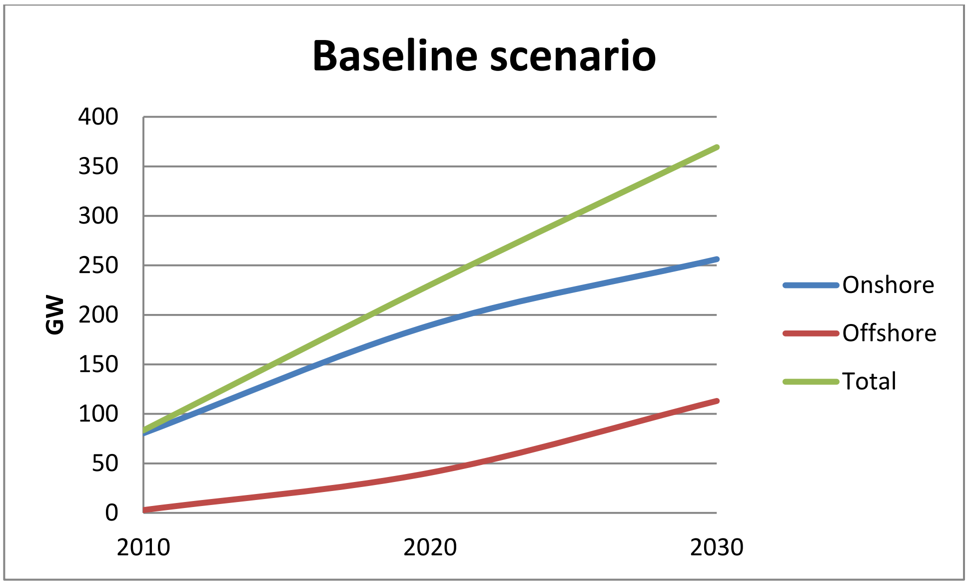

Figure 4 Pan-European wind power development by 2030, baseline scenario

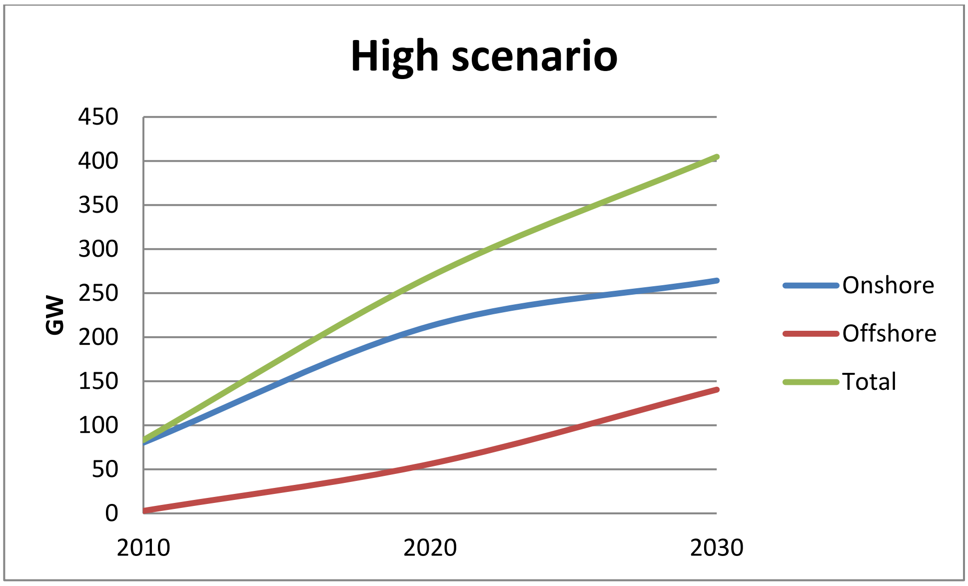

Figure 5 Pan-European wind power development by 2030, high scenario

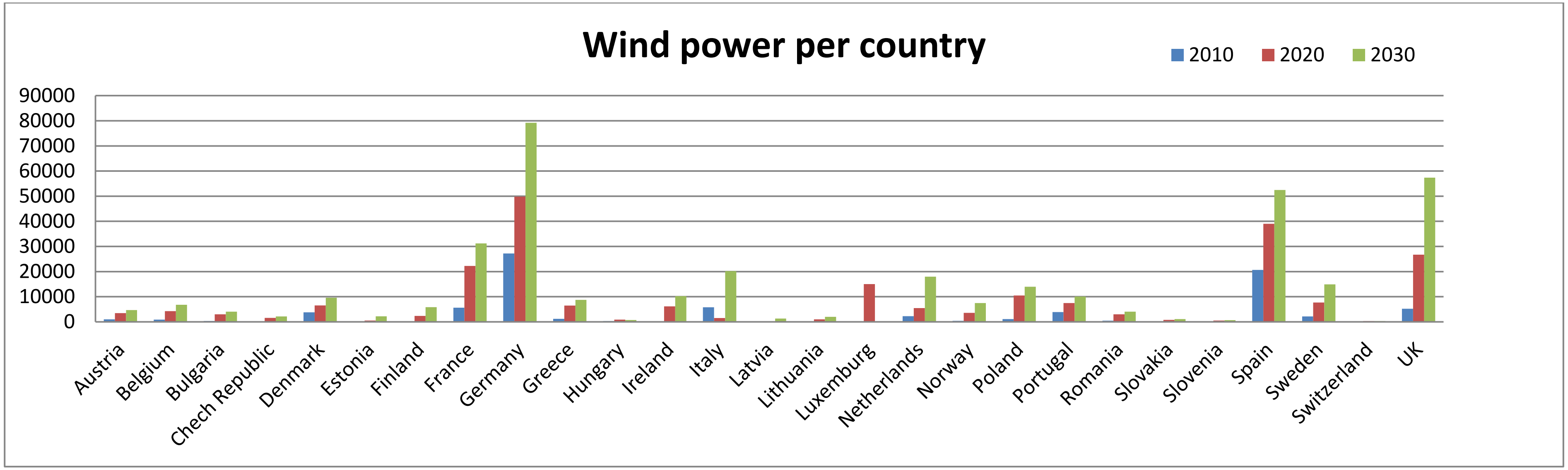

Figure 6 Wind power development per country, baseline scenario

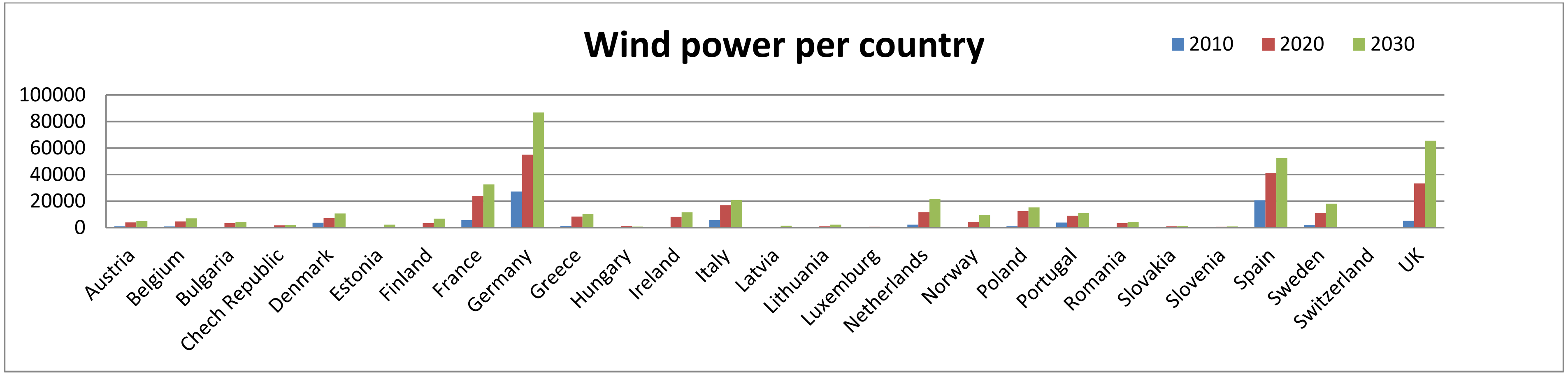

Figure 7 Wind power development per country, high scenario

3 PAN-EUROPEAN WIND POWER TIME SERIES

Another task of this work was to calculate and deliver a data set containing pan-European wind power time series of both forecasted and realised wind power. The time series will cover a year with hourly resolution and will be used in Task 16.2.3 Grid restriction studies and Task 16.2.4 Economic impact studies. In order to reach a pan-European wind power generation map, the offshore wind scenarios were supplemented with onshore wind power development scenarios.

3.1 WIND SPEED TIME SERIES

The wind speed input data come from a climate simulation using the Weather Research and Forecasting (WRF) model and the dynamical downscaling technique developed by Hahmann et al [5], but using Newtonian relaxation terms toward the large-scale analysis (also known as grid or analysis nudging). Initial and boundary conditions and the gridded fields used in the nudging are taken from the NCEP reanalysis [6] at 2.5° × 2.5° resolution. The sea surface temperatures are obtained from the dataset of Reynolds et al [7] at 0.25° horizontal resolution and temporal resolution of 1 day. The simulation covers the period from 1 January 1999 and is regularly updated with hourly outputs. The model is run on an outer grid of spatial resolution of 45 km and a nested grid of 15km, respectively, as it can be seen in Figure 8

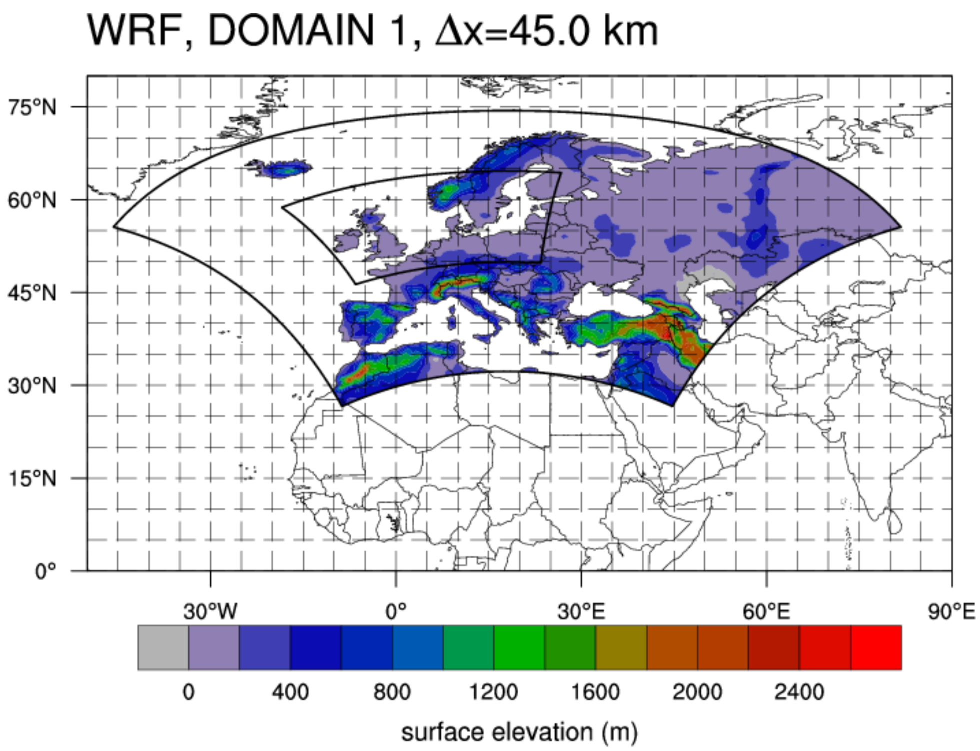

Figure 8 WRF domain and grid configuration

In order to extract the wind speed at the exact location of the points considered – both offshore and onshore – CorWind was used.

The basic idea behind the interpolation of the wind speed values from the grid points to the turbine point can be shown in the figure above. The value at the turbine point is the weighted sum of the value at the nearest grid points. In this simple 1D illustration, the weighting factor α_i for a grid point i is given by

$$a_i = \frac{\Delta x_{j \neq i}}{\sum_j \Delta x_j}$$

Where Δx_i is the difference in longitude (or latitude) of the turbine point from the grid point *i*.

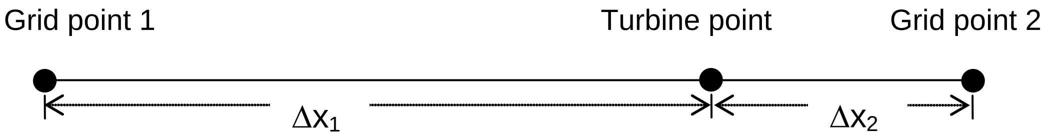

Figure 9 Wind speed value interpolation 1D illustration

For the 2D case, as is used in CorWind, the nearest grid points to the turbine point forms a triangle that encloses the turbine point and an equivalent expression for the weighting factors α_i is used.

3.2 WIND SPEED FORECAST ERRORS

The Scenario Tree Tool, a module developed in the WILMAR project, can simulate for each hour a set of realistic wind speed prediction scenarios on hourly basis and up to day-ahead, i.e. 36 hours. It is based on [9]. The simulations include [8]:

- The autocorrelation of the wind speed forecast errors over the forecast length for specific wind speed measurement point.
- The correlations of the wind speed forecast errors between individual wind speed measurement points for the individual forecast hours.

While STT can calculate several scenarios, in this work it was used only to calculate the wind speed forecast errors for all the wind power locations, both onshore and offshore, in all scenarios (base & high, 2020 & 2030).

STT assumes that the accuracy of wind speed forecasts errors in different regions and correlations of wind speed predictions are known. In order to supply that information, persistence forecasts has been assumed and used to quantify the wind speed forecast errors for all forecast horizons.

The wind speed forecast errors are simulated using an ARMA(1,1), i.e., Auto Regressive Moving Average series, defined as:

$$X(0) = 0$$

$$Z(0) = 0 \quad (1)$$

$$X(k) = \alpha X(k\text{-}l) + Z(k) + \beta Z(k-1)$$

where

$X(k)$ = wind speed forecast error in k-hour forecast

$Z(k)$ = random Gaussian variable with standard deviation σ_z

α, β = parameter of the ARMA-series.

The values for the ARMA parameters, as well as for the standard deviation, were supplied by Energinet.dk and they were estimated in the SupWind (supwind.risoe.dk) project based on the power forecasts used for the daily operation at Energinet.dk.

The average correlation between points with distances ranging from 50 to 3000 km is shown in Figure 11.

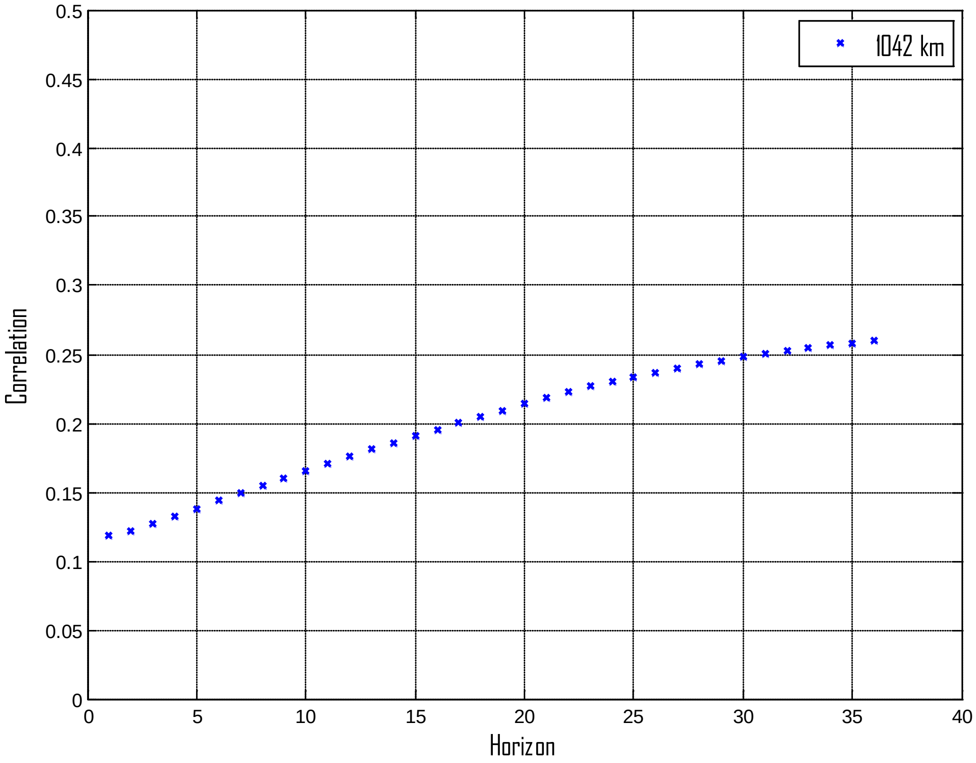

Figure 10 Average wind speed forecast error correlation across Europe (the average distance is 1042 km)

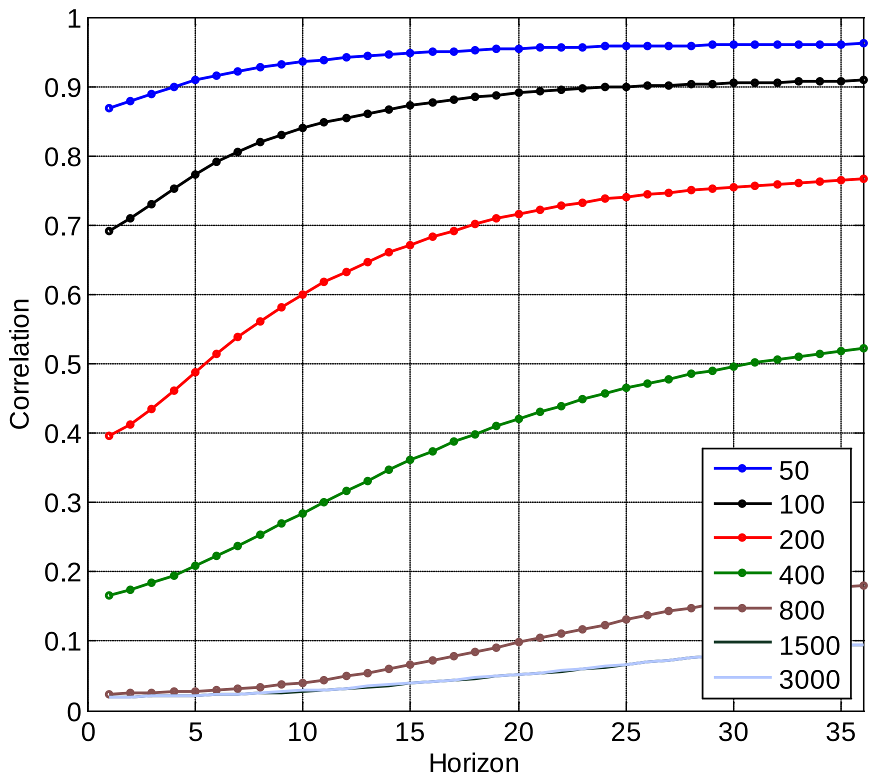

Figure 11 Correlation between forecast errors for different forecast lengths and distances between sites

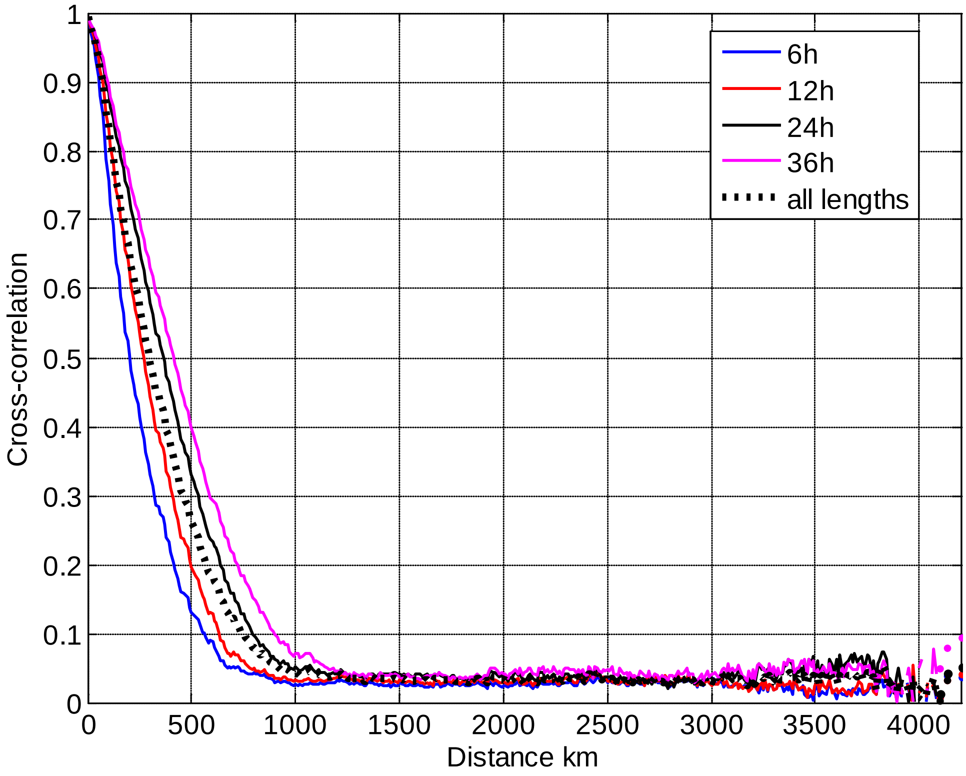

Figure 12 Cross-correlation of wind speed forecast errors as function of distance

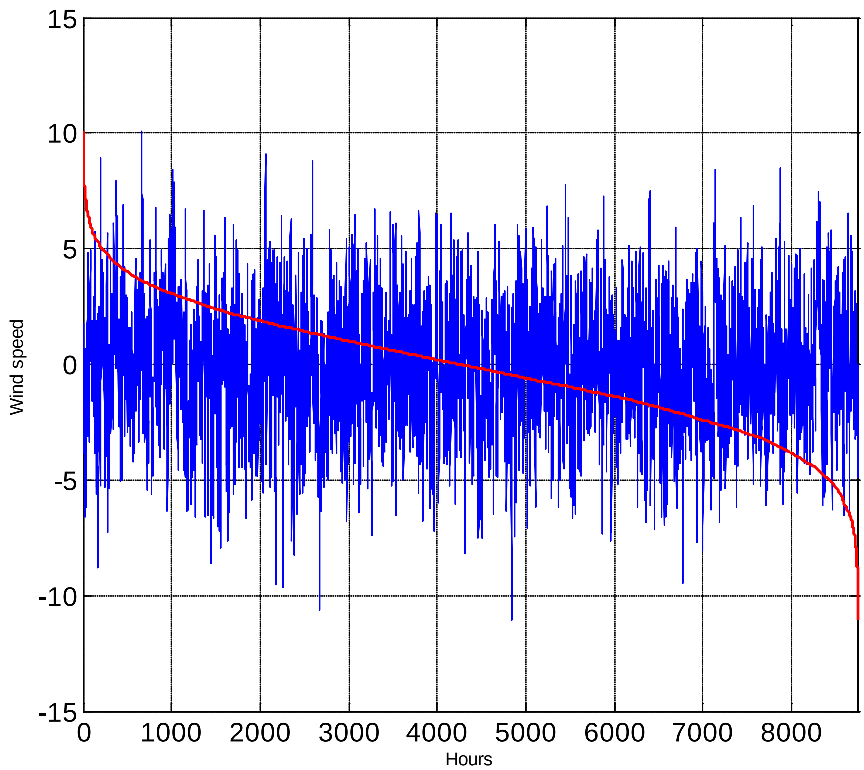

Figure 13 Wind speed forecast error time series and distribution for Horns Rev 2 wind farm

The cross-correlation, over distance, is shown in Figure 12. The correlations have been averaged over 10 km bins.

The output from STT is the wind speed forecast errors, given in absolute values. There is a wind speed forecast error time series for each point. Then the forecasted wind speed is obtained by adding the forecast error time series to the corresponding wind speed.

An example of the resulted wind speed forecast error time series together with the distribution of the forecast error is given in Figure 13. The chosen example is for Horns Rev 2 offshore wind farm in Denmark.

3.3 WIND POWER CURVES

The transformation of wind speeds into power has been done using aggregated power curves. In order to represent more accurately the ground elevation of the wind power regions, three classifications of the wind power regions were used: lowland (up to 400m above sea level), upland (over 400m above sea level) and offshore [10]. For each terrain type, an aggregated wind power curve was used. For the onshore wind power, since the geographical aggregation of wind power is similar to the one used in the TradeWind project, the power curves corresponding to lowland and upland were used. For the offshore part, since the aggregation is done to wind farm level, a power curve supplied by Energinet.dk, representing the aggregation of a typical large offshore wind farm, i.e. Horns Rev 2, was used. The power curves are given in Figure 14.

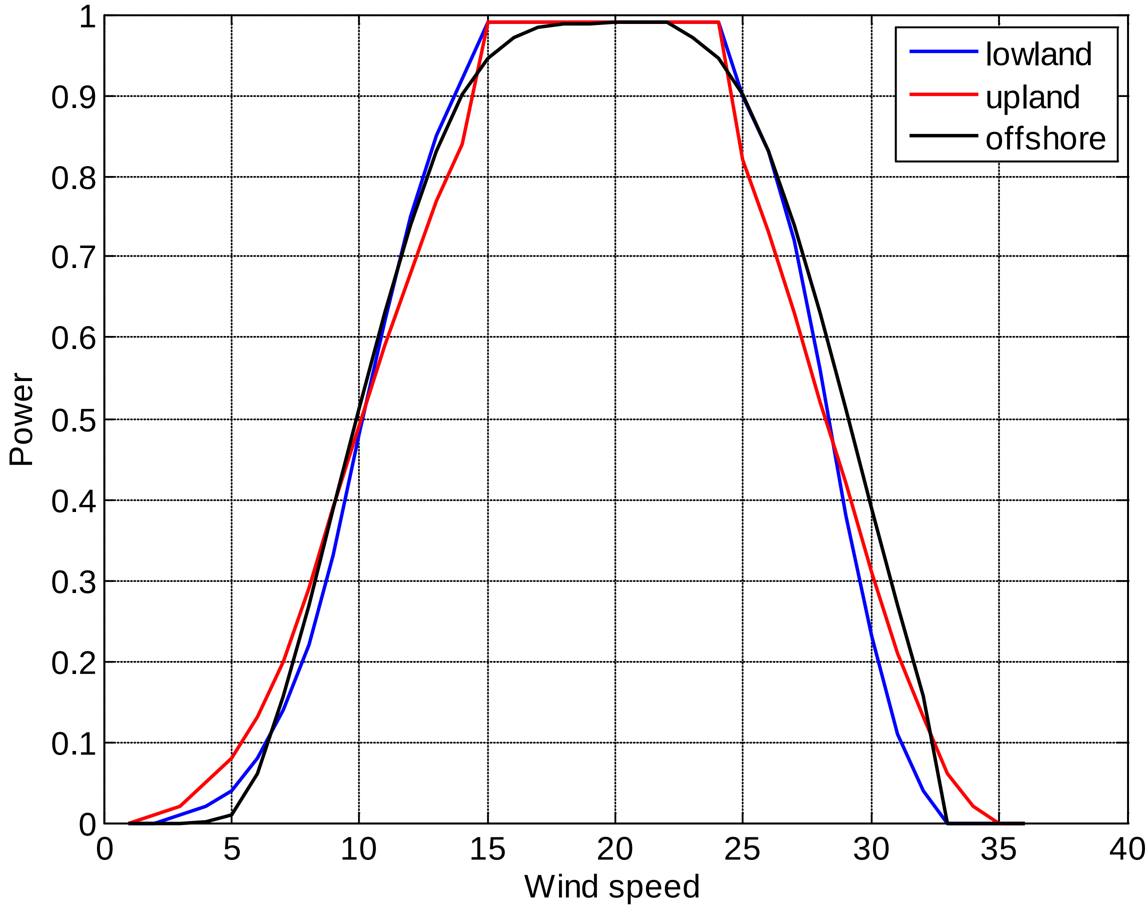

Figure 14 Aggregated wind power curves

Using this approach, a wind power region can be lowland, upland, or a combination of those. The classification of the wind power regions, i.e. lowland, upland or combination considered here is the same as in the TradeWind project.

3.4 WIND POWER TIME SERIES

A data set containing forecasted and “realised” wind power time series, for all Europe, has been created. For the maximum case, i.e. 2030 high scenario, there are 475 entries in the data set, corresponding to 475 wind power points in Europe, aggregated at wind power region level for the onshore wind power, or to wind farm level, for the offshore wind power. Offshore wind power plans for the Mediterranean Sea have not been included here. The distribution curve of the pan-European wind power forecast error is shown in Figure 15.

The influence of the spatial distribution of wind power over the wind power forecast error is shown in Figure 16, where de distribution of the wind power forecast error for Horns Rev 2 wind farm and for all Denmark is plotted. One can see that when looking only at Horns Rev 2 wind farm, the wind power forecast error is higher. This is even more pronounced when looking at larger countries, like Spain, where we compare de wind power forecast error distribution from one wind power region, i.e. E1 and the whole country.

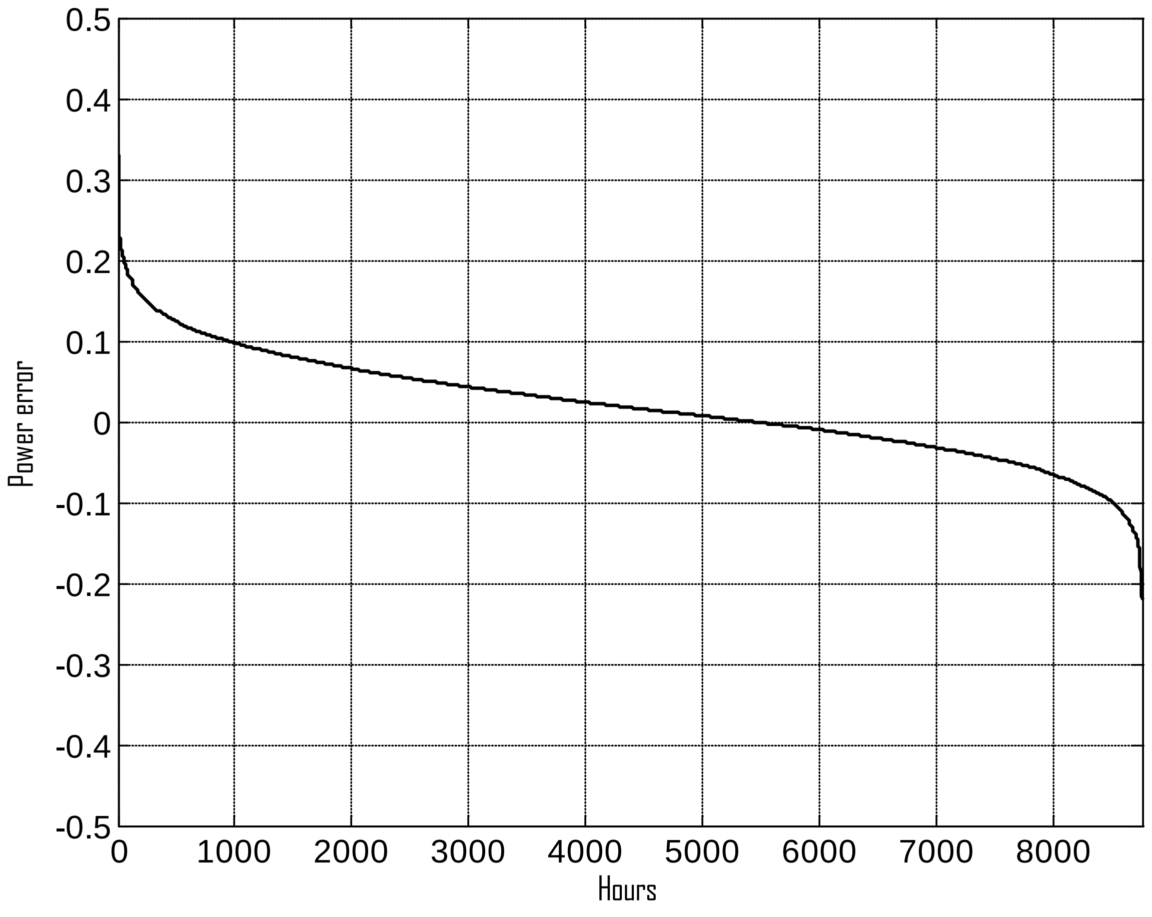

Figure 15 Wind power forecast error duration curve for all Europe

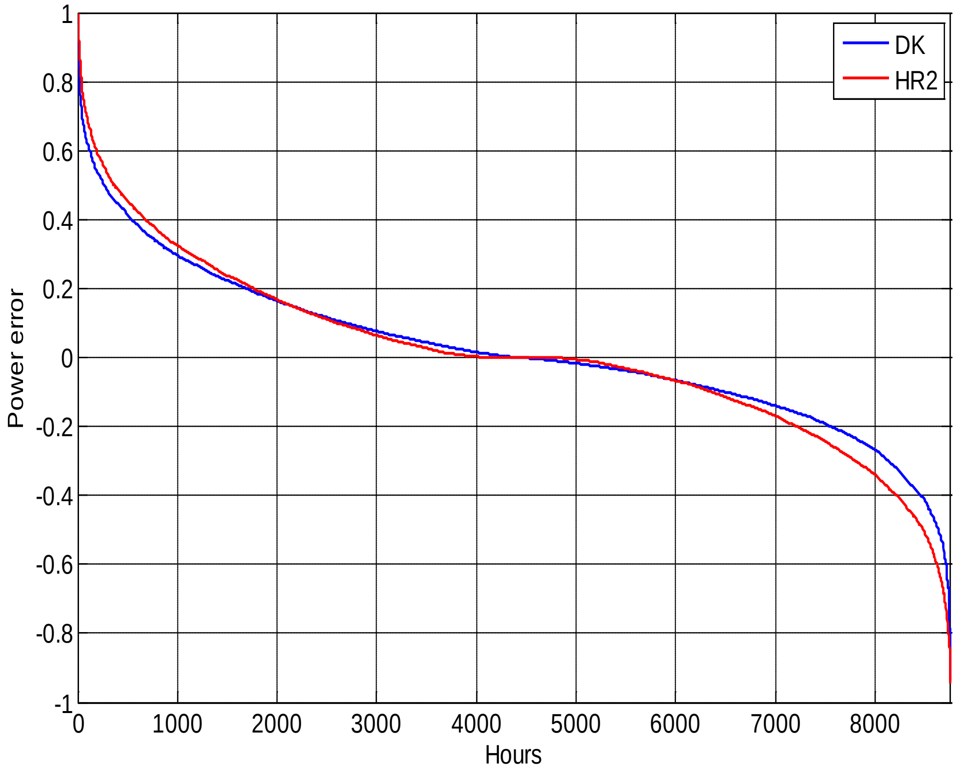

Figure 16 Wind power forecast error distribution for Horns Rev 2 wind farm and whole Denmark

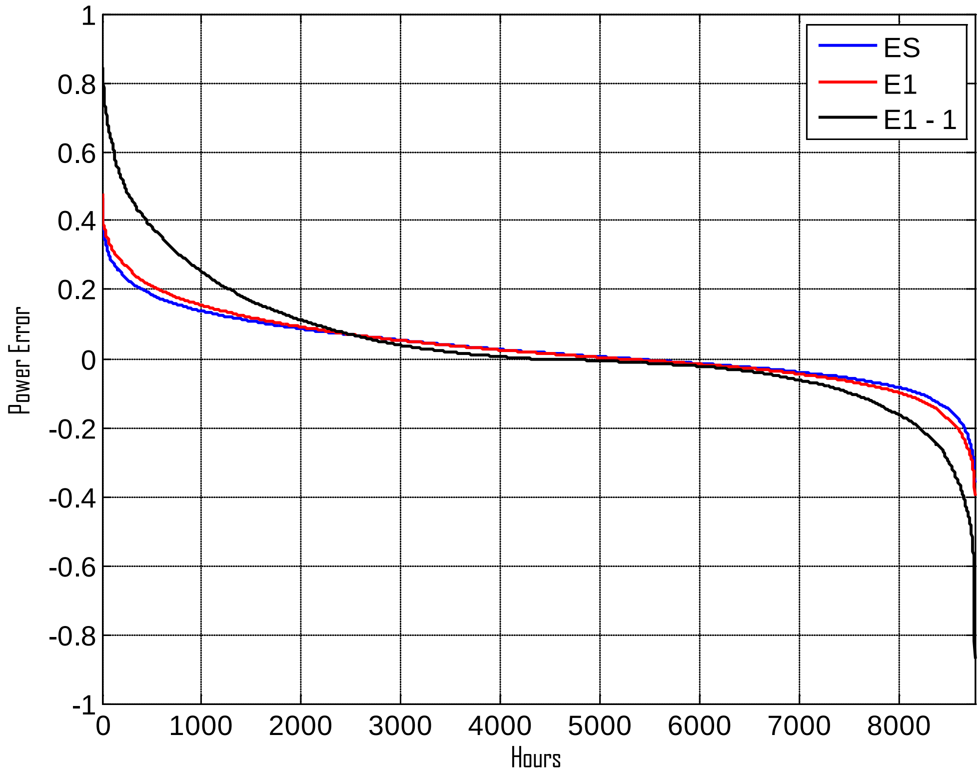

Figure 17 Wind power forecast error for one wind power node, one wind power region and the whole country

4 CONCLUSIONS

Offshore wind power development scenarios for 2020 and 2030 were developed. The work has focused on North Europe. Two cases – baseline and high – were considered. The scenarios indicate an installed offshore wind power capacity of approx. 40 GW in the conservative case and a little over 56 GW in the "high" scenario by 2020. When looking to 2030, the numbers are 113 and 141 GW respectively. The offshore wind power development database created includes also the geographical coordinates of each offshore wind farm that is currently there or will be by 2020/2030. In order to be able to create the time series needed for the economic impact assessment, the offshore wind power scenarios were complemented with the projected European onshore wind power development. For the onshore wind, wind power was aggregated to grid node or wind region level.

Using the scenarios developed, a database with forecasted and "realised" wind power for whole Europe was created. The database contains annual time series for each wind power point in the 2020 and 2030 scenarios. The time series have hourly resolutions.

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